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Development of the wind power in Brazil: Political, social and technical issues

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ABSTRACT

This paper aims to present a review of the increasing contribution of wind power to the Brazilian electric matrix and an analysis of the main impact on technical, political and social aspects. This work takes into account the state-of-art of the wind power technology, the wind resource potential and the evolution of installed capacity in the country. The institutional programs and the fiscal incentives provided by the Brazilian government are also discussed in this paper, including its impacts on the society. We have reviewed national and international reports and relevant scientific papers to realize this work. The analysis shows that electric crisis in 2001 led the Brazilian government to develop new energy policies that supported the rapid growth of the wind industry from imported technology. Later on in the year 2004, the government mandated that the technology be developed within the country. It is expected that from 2011 (of approximately 1500 MW) until 2021 the installed wind capacity would increase by a factor of 600%. However, the national technology acquisition and development is still incipient. It is important to produce locally wind turbine components and is highly desirable to increase collaboration between industries and universities in the country.

Contents

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1. Introduction

Since the oil crisis in the 1970s, and lately the impact of global warming on our environment, the search for renewable energy sources has accelerated substantially. However, the current global dependence on fossil fuels for the generation of electricity is still dominant and its total replacement seems unrealistic in the near future.

Brazil has an area of 8.5 million km^2 and a population of approximately 200 million. Because of the rapid industrialization and a better life-style for the people, the demand for electricity is increasing exponentially. However, at the present time almost 70% of the total generating capacity is from hydroelectric sources and additional sources of hydropower are diminishing [1–3]. Due to the impact of large hydraulic power projects on the environment, the search for other renewable energy sources, such as wind, biomass, solar and wave, are required to exploit.

Another challenge faced in Brazil is the recurrence of prolonged droughts for periods of two to three years, leading to shutdown of hydroelectric plants due to shortage of water in the reservoirs. This led to the blackouts in 2001 and 2002 which resulted into social and political backlash. Therefore the federal government instituted a wind energy program named PROEOLICA [4]. The aim of the program was to install 1050 MW wind capacity, and expected to alleviate electricity shortage. It should be emphasized here that, especially, in the Northeast of the country there is a good complementarity between water and wind resources. In other words, when there is drought, the wind are stronger and steadier during same period [3,4]. However, this program was not successful due to insufficient fiscal incentives to industry [5].

In 2004, another program for renewable energy sources, called PROINFA, was created from which wind power benefited the most [6]. At the end of 2013 more than 3300 MW of wind capacity has been installed and is distributed over 140 wind farms throughout the country [7].

The electric matrix can be approached from different perspectives. Among the most important are: social, technological development, political and environmental, and energy planning perspectives [8–12].

This work presents the state-of-art of wind power technology considering the technical, political, and social aspects. We also describe repercussions in the implementation of wind power and its important role in the development of the country.

This paper is structured into six sections. Section 1 consists of the introduction; the share of wind power in the Brazilian electric matrix is described in Sections 2 and 3 describes the Brazilian wind potential taking into account the wind resource and the installed generating capacity. Section 4 describes the main political decisions needed to meet the wind energy development in the country. In Section 5, several societal aspects that could help meet the goal of sustainable development outlined by the government are described. Finally, Section 6 presents the concluding remarks.

2. Present role of wind power in the electric matrix

Until about 2001, more than 90% of energy generation was generated from hydroelectric plants and the remaining came from coal-fired generators, and some quantity (from gas) was imported from a neighboring country [8]. As mentioned in the previous section, a remarkable shift in the electric matrix composition occurred in 2001 when government incorporated the program PROEOLICA [13]. Then in 2004 PROINFA was institutionalized where small-scale hydro, wind, biomass and solar were given incentives. Since then, the country's electric matrix has grown year by year in terms of installed capacity and, also, in the expansion of the distribution network.

Fig. 1 shows a pi-diagram of the electric matrix at the end of 2013. The highest contribution came from the hydroelectric source, 67.89%. The second highest came from thermal plants, comprising mainly of natural gas generators, 28.61%, wind power, 1.7%, and nuclear sources, 1.58% [2].

Another renewable energy source is solar energy with an installed capacity of about 4.9 MW [2]. Even though several institutions are engaged in the development, but as of now it presents an insignificant amount in the energy matrix [10].

Ricosti and Sauer [12] elaborated a study of annually and multi-annually complementarities which demonstrated the advantages of wind energy investments over thermal plants. The obtained results indicated a 200% increase on the per capita energy consumption, from today's 2.5 MWh to 7.5 MWh in 2040.

Furthermore, recent governmental energy planning studies indicate that flexible thermal plants and those not dispatched from the interconnected system due to electrical reasons should not represent restrictions to the flow of energy generated by wind farms [14]. Considering the intermittent nature of wind and solar sources, the *Operador Nacional do Sistema Elétrico* - ONS (National Operator of the Electric System) should maximize wind dispatch-ability. In this scenario, the ONS should provide an arrangement for flexible thermal sources (i.e. gas turbine plants running on natural gas and combined cycle gas turbine plants), with the purpose of stabilizing intermittency, reliability of the electric grid and supply security.

3. Wind energy development

3.1. Energy potential

There have been several studies aimed at estimating wind potential in Brazil. One of the most important published work was in 2001, named Wind Atlas of Brazil [15]. It has been estimated that Brazil has a potential of 143 GW and that it is possible to produce about 272.2 TWh/year (at an average hub height of 50 m). Fig. 2 shows the wind power potential in the five regions of the country. The potential for each of the region is estimated as: Northeast (75 MW), South (41.1 MW), Southeast (29.7 MW), North (12.8 MW) and Center-West (3.1 MW). The strongest and steadiest winds blow in the Northeastern and Southeastern regions of the country with an annual mean speed in order of 8 m/s [15].

Moreover, some Brazilian states have prepared their own wind atlases with detailed information than that indicated in Fig. 2. In 2013, a preliminary version of the wind atlas was presented for the state of Pernambuco, which is situated in the Northeastern region of the country with an estimated wind power potential in

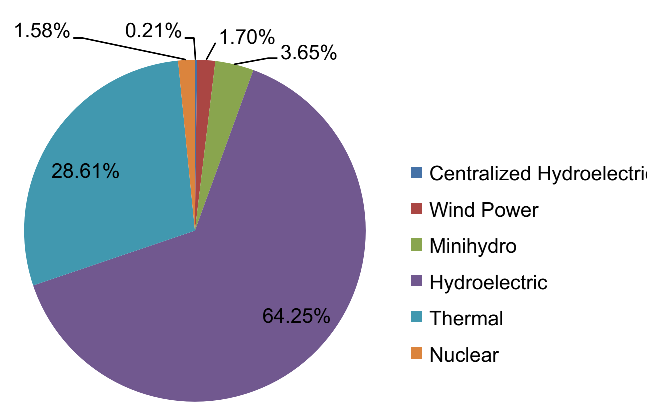

Fig. 1. Brazilian electric matrix in 2013.
Source: ANEEL [2], adapted by the authors.

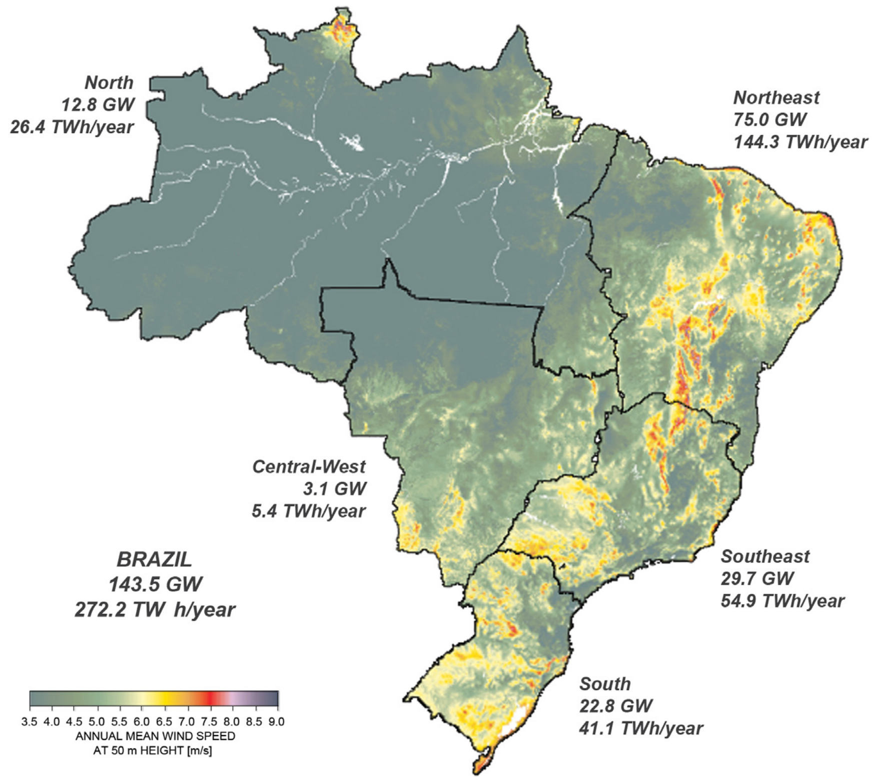

Fig. 2. Wind potential in the five regions of the country.
Source: [15], adapted by the authors.

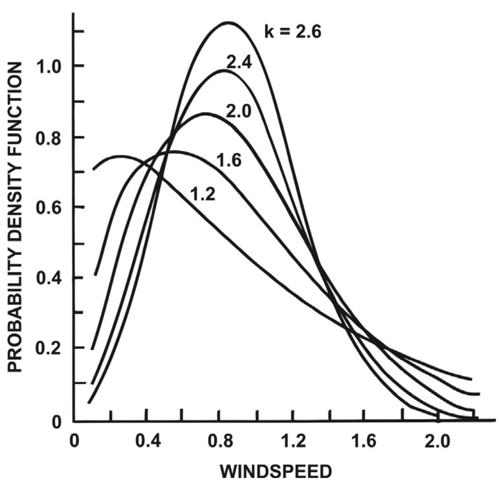

Fig. 3. Weibull probability density function.

the order of 4 GW [16]. Some other studies have confirmed the excellent Brazilian wind power conditions [17–19]. Lucena et al. [20] and recently Pereira et al. [21] have all concluded that if the effects of climate changes are incorporated into the wind atlas, the Brazilian wind potential would become very attractive. According to Lucena et al., the increase in potential could be by a factor of 4.9 and 2.3 for the North and Northeast regions, respectively [20]. As a result of this, the Brazilian wind potential would be sufficient to develop the wind industry until the year 2100.

Furthermore, Dutra and Szklo [22] suggested that the addition of wind capacity at the rate of 1–10 GW/year in the North and Northeast coastal regions would make them very attractive to investors. One important factor that makes coastal regions attractive is logistics, since turbine blades and tower are large in dimensions and weigh tens of tons. Therefore, to transport them by road becomes very expensive and difficult. Thus, siting wind turbines along the coast alleviates this problem.

It is also estimated that the Brazilian offshore wind potential would be around 600 GW at a hub-height of 80 m and at a depth of approximately 100 m [23–26].

3.2. *The Southeast trade winds and its influence on wind speed distribution*

The Northeast coastal region of Brazil, lying in between the latitudes of about 5°–15°S, is influenced by the Southeast trade winds. Studies of wind data distribution by Rohatgi et al. [27] have observed that the Weibull probability density function (a two parameter function) is quite different from the European or North American sites.

The Weibull density function (Fig. 3) [28–33] is expressed as

$$f(V)=\frac{k}{c}\left(\frac{V}{c}\right)^{k-1}\exp\left[-\left(\frac{V}{c}\right)\right]^{k}$$
$$\text{when } k>0;\; V>0;\; c\geq 1 \tag{1}$$

where k=shape parameter; c=scale parameter. The cumulative density function is expressed as

$$F(V)=1-\exp\left[-\left(\frac{V}{c}\right)\right]^{k} \tag{2}$$

The Weibull shape factor, k, for most of the European and North American sites is in order of 1.8–2.2. However, the shape factor for the Northeast coastal sites in Brazil has been estimated as high as 4 or more. The higher values of shape factor indicate that the wind speed is steadier, that is, the variability of wind speed is lesser. The shape factor also influences the energy pattern factor. The energy pattern factor is defined as the ratio of sum of cube of the wind

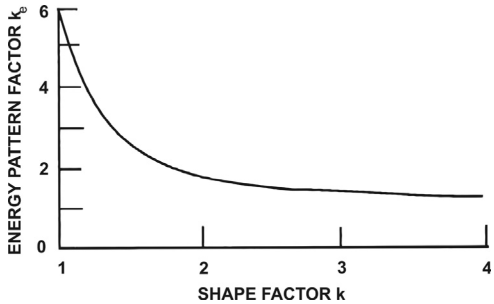

Fig. 4. Relationship between the shape factor and the energy pattern factor.

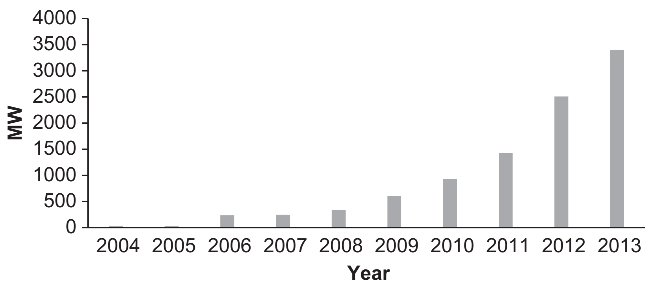

Fig. 5. Growth of the Brazilian wind power capacity: 2004–2013.
Source: ABEEólica [7], adapted by the authors.

speed to the cube of the mean wind speed. It can be written in function of shape parameter as

$$K_{EF} = \frac{\Gamma(1+(3/k))}{\Gamma^3(1+(1/k))} \tag{3}$$

where $\Gamma(\ )$ is the gamma function.

It can be seen from the above equation that higher the shape factor, the lower would be the energy patter factor. For the sites in the Northeast of Brazil, the energy pattern factor is as low as 1.2–1.4, whereas the sites in the Europe or in the North America have energy pattern factor in order of 2–2.2. Fig. 4 shows the relationship between the shape factor and the energy pattern factor [27]. It is expected that the performance of wind turbines in the Northeast coastal region of Brazil would be higher than those in the European or North American sites.

3.3. Evolution of wind power in Brazil

The first wind turbine was installed and commissioned in 1993 at the island of Fernando de Noronha. The turbine (hub height 23 m and 17 m three-bladed rotor) had a rated power of 75 kW [34]. From that year until 2003, the installed capacity in the whole country was only about 24 MW. This capacity, besides the island, was distributed among Morro do Camelinho in the state of Minas Gerais; Taiba, Prainha and Mucuripe in the state of Ceará; Palmas in the state of Paraná; and Vila de Joanes in the state of Pará [35].

However, with the implementation of PROINFA program in 2004 until the end of 2012, wind power has grown exponentially as illustrated in Fig. 5. At the end of 2013 the total capacity was more than 3300 MW, distributed among 140 wind farms all over the country [7]. Almost 60% of the total installed capacity is in four states: Ceará, Rio Grande do Sul, Rio Grande do Norte and Santa Catarina [2].

3.4. Rapid development of the wind industry

Due to the large wind energy potential in the country and availability of loan to foreign wind turbine manufacturers provided by a national bank, BNDES –*Banco Nacional de Desenvolvimento Econômico e Social* (National Bank for Economic and Social Development), many European and other wind turbine manufacturers showed interest and opened their subsidiaries in the country. Specifically in the last three years, rapid growth took place in the fabrication of the wind turbine components. The 2011 BNDES annual report mentions a significant growth of wind industry by providing loans to new wind equipment suppliers, such as: Acciona, Alstom, IMPSA, Gamesa, GE, Siemens, Suzlon, Vestas, Wobben and WEG [36].

However, in December 2012, BNDES placed an additional condition that the loan would only be given to those manufacturers who can comply with 60% of the components made in Brazil [37]. Table 1 shows the annual production of wind turbine companies/manufacturers of the components.

Table 1
Wind turbine companies and manufacturers of the main components.

Company	Capacity	Location
Wind turbine companies		
Alstom	300 MW/year	Bahia
Acciona	300 MW/year	Bahia
Gamesa	300 MW/year	Bahia
Impsa	600 MW/year	Pernambuco
Wobben	500 MW/year	São Paulo
Turbine blade manufacturers		
Aeris	240 blades/year	Ceará
Tecsis	6492 blades/year	São Paulo
Wobben	300 blades/year	São Paulo
LM Wind power	900 blades/year	Pernambuco
Wind tower manufacturers		
Alstom	120 towers/year	Rio Grande do Sul
Brasilsat	120 towers/year	Paraná
ICEC	100 towers/year	São Paulo
INTECNIAL	80 towers/year	Rio Grande do Sul
Engebasa-SAWE	173 towers/year	São Paulo
Máquinas Piratininga	150 towers/year	Pernambuco
Tecnomaq	200 towers/year	Ceará
RM Eólica	200 towers/year	Pernambuco
Wobben	200 towers/year	Rio Grande do Norte

It is noteworthy to mention that wind turbine manufacturer Wobben has installed 1 GW capacity in 2012 [38]. According to Dutra and Szklo [39], manufacturers of the wind turbine components described in Table 1 would be able to meet the goals set by PROINFA until 2020.

3.5. Wind industry in 2013 and beyond

There are prospects of new companies like GE to manufacture about 200 turbines per year in the state of Bahia in the state of Bahia [40,41]. Furthermore, some of existing manufacturers in the country have already announced their expansion plans. These are: (1). a new blade facility (Aeris) in Bahia to manufacture 2000 blades per year [42]; and (2) Gamesa to manufacture nacelles in order of 400 MW/year [43].

The port of Suape in the state of Pernambuco has attracted number of the wind turbine manufacturers: RM for the tower, LM for the blades and IMPSA for the nacelle, generator and the hub. It is important to mention that the Brazilian government agencies such as FINEP and FINAME have given financial incentives for the development of a national wind industry. Under these policies, there are also initiatives by the Federal University of Pernambuco (UFPE), and companies such as CHESF and IMPSA to develop a national technology for wind turbine components.

Finally, it is important to mention the factories under construction, for example: Torrebras which would have a capacity to produce

about 220 towers/year in Bahia; RM Eólica has undertaken the construction of the first flange factory in Brazil in the state of Pernambuco [44]. Another well-known wind turbine manufacturer Vestas is constructing a manufacturing facility to produce 800 MW/year in the state of Ceará [45].

4. Socio-political aspects

From the beginning of 19th century to 1950s, the Brazilian electric sector was privately managed. But the growing demand for electricity with the fast urban-industrial developments forced the federal and state governments into the electric sector. The sector became a vertical hierarchy where generation, transmission, and distribution were controlled by the government until 1995 [46].

From the 19th century to the mid-1950s, the Brazilian electric sector was privately managed. Due to the growing demand for electricity with fast urban-industrial developments, the electricity sector began to be administered by the federal and state governments. The sector became a vertical hierarchy where generation, transmission, and distribution were controlled by the government until 1995[46].

4.1. Changes in the electricity sector in the 1990s

The political and institutional changes that occurred in the 1990s meant that the system had changed from vertical to horizontal integration, paving the way for the private investments into generation, transmission and distribution of energy [46,47]. As a result, ANEEL, *Agência Nacional de Energia Elétrica* (National Agency of Electric Power) was created in 1997 on the recommendations of a consulting company under the auspicies of the MME – *Ministério de Minas e Energia* (Ministry of Mines and Energy). This agency was created with the aim of overseeing and regulating the production, distribution and commercialization of electric power [46].

4.2. Sustainable use of wind power

The role of ANEEL was further extended by the government to include electricity into the environment, social justice, employment and economic development so as to attain a sustainable development [46]. As a result of the law 10848, the regulatory framework of ANEEL that was implemented in 1997 was further modified in 2004 [48]. Therefore, the free market philosophy was implemented such that energy would be sold to the lowest bidder and this way the end consumer would pay a cheap price.

The program PROINFA was initiated in 2002 to diversify the national electric matrix. The first phase of the program involved the implementation of 3300 MW of renewable energy divided among small hydro, wind, and biomass. It was guaranteed that the generated energy would be bought during 20 years as feed-in tariff system by the National Electric Company (ELETROBRAS). Under this system, the energy generated from each renewable source would be sold at a different price. For example, usually energy generated from the wind has a lower tariff rate than that produced by biomass or photovoltaic source. The feed-in tariff offered by ELETROBRAS to buy power for electrical energy produced by biomass was too low, and, as a result, only 685 MW was contracted. Hence, in order to fulfill the objective of implementing 3300 MW of renewable energy, small hydro and wind sources were contracted for 1191 MW and 1422 MW, respectively [39]. The first phase of the program would end in 2022.

The second phase of the program PROINFA aims to produce 10% of the energy from renewable sources in a 20 year period. In this phase the tariff would be based solely on competitiveness among the various renewable sources. It is envisaged that the energy sold would increase by 15% each successive years, including a limit of 5% in the accumulated tariff increment on the energy sold to the final consumers [39].

The feed-in tariff system adopted in the first stage of PROINFA was also adopted by several European countries at the early stages of the renewable energy development [49]. The feed-in tariff scheme was first implemented in Germany with the primary objective of creating market for renewable energy sources [50]. Although the system is characterized by being expensive since the price is determined by the cost of energy generated by these sources, i.e. there is no fixed price [51]. It is however a secure investment for these alternative energy sources. This measure taken by the government would explain the rapid development of the wind industry in Brazil.

On the other hand, at the second stage of PROINFA the tariff would be characterized by the choice of the cheapest projects, which would eventually lead to competition between enterprises which in turn would be obligated to invest in updating or modernizing their power plants. This affirmation can be demonstrated in Fig. 6, which illustrates the reduction of MWh values dealt in energy auctions since the beginning of PROINFA. For this the US dollar to the Brazilian real exchange rate used is (R$ 2.30 BRA = 1 USD).

According to the ten-year energy plan (PDE) presented by EPE – *Empresa de Pesquisa Energética* (Energy Research Company), it is estimated that Brazil would have an increase of 14200 MW from 2011 to 2021 [52]. This forecast is based only on annual auctions.

Furthermore, Rule number 482 of ANEEL establishes the general assessment conditions for mini- and micro-distributed generation to the electricity distribution and compensation systems, thereby encouraging autoproduction of electricity.

In 2013, the P&D – *Pesquisa e Desenvolvimento* (Research and Development) call no. 17/2013 “National technology development of wind generation” was launched by ANEEL to incentivize constant research and innovation to face the technology challenge of

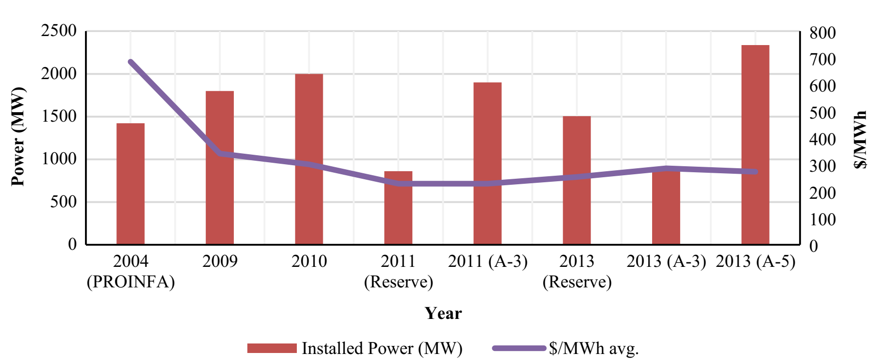

Fig. 6. Average cost per MWh and installed power (MW) (2004–2013).

the electric sector [2]. In this context, concessionaires responsible for distribution, transmission and/or energy generation must annually apply a minimum percentage of its net operating revenues in the Research and Development Program of the Power Sector. Thus, the participation of the Brazilian society reinforces its presence not only in energy planning, but also in the national technology development, fulfilling this way the expectations outlined by the government.

5. Renewable energy sources and sustainable development

The concept of sustainable development basically embodies four domains: environmental, ecological, cultural/social and political. In other words, sustainable development is the development that meets the today's needs without compromising the needs of future generations [53].

The implementation of alternative energy sources, wind power specifically, to generate energy would alleviate the environmental issues currently in the world such as depletion of water other natural resources and global warming. Moreover, from a socio-political-economic point of view, the implementation should be accompanied by systematic changes in the areas of transport, agricultural practices, energy conservation and consumption in households and industries [54,55]. This would require adjustments in the life style of individuals and the society as a whole, changes in perceptions and practices rather than focusing on profit criteria.

In Brazil, most of the electricity is generated from renewable sources. Moreover, about 17% of the carbon emissions arises from the electric sector. The reminiscent emissions come from the following sectors: (1) internal combustion engines in vehicles (38%); (2) manufacturing industries (32%); and (3) service sector, agriculture, and others (13%) [56]. Therefore, it can be seen that the electric sector has been the third main driver of carbon emissions, but with the inclusion of more renewable and clean sources in the electric matrix, this percentage (17%) from carbon emissions will tend to decrease. Furthermore the costs involving the transition to a renewable and sustainable energy matrix could be seen as a real possibility for the national economic expansion involving the industrial, technological and social sectors [57].

On the other hand, a better electricity planning and usage would diminish the chances of blackouts, serve remote areas or islands even though new investments in electric transmission lines may be demanded and save scarce resources for future generations [58]. This way, in an attempt to improve the rational use of electricity, PROCEL - *Programa Nacional de Conservação de Energia Elétrica* (National Program for Energy Conservation) was established in December 30, 1985 by the Ministry of Mines and Energy and the Ministry of Industry and Trade of Brazil [10]. Afterwards a similar program Procel ReLuz was established, this time with the aim of improving the efficiency of electric equipment and public lighting points in the country.

The capitalist economies, including Brazil, seek to the increase profit by improving the efficiency of the production processes and equipment. This would normally lead to increased unemployment due to technology modernization [59]. However, the adoption of sustainable development would not lead to unemployment since it balances the modernization of industries by recycling waste and other byproducts into the system. Therefore, the manpower displaced by modernization would be reemployed in recycling and recuperating energy and wastes.

In the case of the wind industry, considering the last indicators of wind power, it is possible to estimate a yearly growth rate of about 10–15%. According to the Brazilian government policy, it is intended to auction at least 2 GW annually until 2020.

As it has been previously discussed, the Brazilian electric matrix is predominantly hydroelectric. This source presents a high energy density characteristic per turbine operating on regular regimes, thereby leading the equipment to have a long lifespan. Considering the integration of wind power into the electric matrix, the turbines have a low energy density and a lower lifespan than the hydraulic turbines. In this regard, the use of wind power represents the greatest potential source of residue generation, where the reuse of these materials is a scientific-technical challenge in such a way that it becomes environmentally sustainable.

The present technology requires a number of turbines in a wind farm, therefore it is necessary to reuse material components after decommissioning the wind turbines. The following aspects are considered in this case: (1) the lifespan of a wind turbine is considered to be at least 20 years [51,60]; (2) the quality and properties of the materials; (3) repowering and/or recycling components of obsolete wind turbines.

6. Concluding remarks

The national energy crisis in 2001 led the Brazilian government to incorporate new renewable and sustainable energy sources to generate electricity. Since the implementation of the PROINFA program more than a decade ago, the wind industry has experienced exponential growth from a few megawatts to more than 3300 MW at the end of 2013. Though the share of wind power in the electric matrix is still only about 1.7%, but it is expected to reach 10% in the next 15 years or so.

The government policies for national wind energy development are creating a modern industry. These policies are in line with the sustainable development and as such meets social justice, environmental conservation and the creation of green jobs. Thus with a sustainable development, the continuous energy generation is also assured where the occurrences of the blackouts (possibly due to long dry weather) would also be avoided. Therefore, the integration of renewable sources such as wind into the Brazilian electric grid can be said to be a win-win situation.

From the social and political points of views, only the privileged parts of the society could participate in the energy industry a few decades ago. Since the energy crisis of 2001, changes in the policies led the whole society to have a share in the resources of nature.

The Brazilian government has been making efforts for scientific and technological development by making investments in science and engineering education. Nevertheless, the country still lacks qualified human resources able to develop a sound national wind technology development.

It is expected that in the coming years almost all the wind turbine components and accessories would be manufactured in the country and, hopefully, the participation of the government and the fiscal incentives involved would give full support to the growth of the wind industry.

Acknowledgments

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